The moderating effect of stress on the relationship between air pollution and self-rated health in minorities

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Abstract

Minorities have long been discriminated against in the United States, and redlining policies pursued in the 1920s-60s prevented African-Americans from moving outside polluted inner city neighborhoods. This resulted in the siting of many environmentally hazardous facilities in these neighborhoods, exposing minorities to increased levels of air pollution that persist today. Exposure to air pollution is associated with low birth weight, asthma, diabetes, heart attacks, strokes, and obesity. Minorities also experience higher levels of perceived discrimination, a reliable predictor of chronic stress. Chronic stress leads to constant output of the stress hormone cortisol, which increases blood pressure, insulin resistance, cholesterol, and weight, and decreases immune function and memory. The effects of a lifetime of increased stress are hypothesized to compound the effects of disproportionate exposure to air pollution and make African-Americans more susceptible to diabetes, heart disease, stroke, obesity, and asthma than Whites. These disparate health outcomes culminate in a 10% decrease in life expectancy for African-Americans compared to their White counterparts (Centers for Disease Control and Prevention, 2015).

This study sought to explore the effects of stress on the well-established relationship between air pollution and health by analyzing self-reported health and stress data. Overall, health outcomes were best predicted by "classic" biologic indicators, such as age and BMI, and were somewhat well predicted by socioeconomic determinants of health such as income and education. Self-rated general health was well accounted for, with almost 30% of the variation in general health explained by our independent variables. We also found that respondents reporting higher stress levels were strongly more likely to report worse overall health and respondents living nearer to facilities were moderately more likely to report worse general health.

Introduction/Background

In this paper, we explore the relationships between pollution, stress, and health in American minorities. In the United States, racial minorities have long been discriminated against in a multitude of ways, including unequal access to education, employment, and healthcare, and unequal exposure to environmental hazards (Chakraborty, Collins, Grineski, Montgomery, & Hernandez, 2014; Clark, Millet, & Marshall, 2014; Gioielli, 2014; Sicotte & Swanson, 2007; Zwickl, Ash, & Boyce, 2014). These inequalities are rooted in an extensive national history of racism and discrimination, intensified by redlining African-American residents into polluted and impoverished inner-city neighborhoods where environmental hazards were cited in the 1920s-60s, while simultaneously funneling money to comparatively rich, White suburbs (Gioielli, 2014). This general population distribution is seen in and around American cities today, and minorities still face increased exposure to pollution, especially air pollution (Brulle & Pellow, 2006; Chakraborty et al., 2014; Clark et al., 2014; Gioielli, 2014; Jones et al., 2014; Sicotte & Swanson, 2007; Zwickl et al., 2014). Race is the strongest mediating factor for disproportionate exposure to air pollutants, over income and education level (Clark et al., 2014).

Exposure to air pollution is linked to many health problems. Nitrogen oxides irritate mucosal membranes, causing asthma attacks, increasing susceptibility to respiratory infections, and contributing to the development of asthma (US EPA, 2016). Air pollution is also linked to increased blood glucose, insulin resistance, increased weight, mitochondrial diabetes in rats, and the development of lung cancer (Kim & Lee, 2014; Sicotte & Swanson, 2007). Nitrogen oxides activate inflammatory genes, and this inflammation accompanies diseases such as chronic obstructive pulmonary disorder, cystic fibrosis, asthma, interstitial lung disease, and acute respiratory distress syndrome (Edwards & Myers, 2007). NO_2 exposure is also associated with

low birth weight, especially for minority mothers (Li, Laurent, & Wu, 2016). Additionally, the physiological stress of defending the body against environmental stressors – in this case, air pollution – may make the body worse at turning off these defense mechanisms when exposure is low, consistently elevating blood glucose and blood pressure, as well as accelerating the progression of obesity and type II diabetes (McEwen, 1998).

Stress response is determined by allostatic load, "the wear and tear on the body and brain resulting from chronic overactivity or inactivity of physiological systems that are normally involved in adaptation to environmental challenge" (McEwen, 1998). Allostatic load is comprised of three physiological responses: frequent stress (type 1), failed shut-down (type 2), and inadequate response (type 3) (McEwen, 1998). Type 1 response can lead to types 2 or 3, type 2 is associated with hypertension, diabetes, obesity, and dendritic atrophy, and type 3 is associated with autoimmune disorders, inflammation, chronic fatigue syndrome, and fibromyalgia (McEwen, 1998).

Stress is characterized by the release of the stress hormone cortisol, which can be beneficial in the short term, temporarily sharpening memory and mobilizing stored energy (Cacioppo & Freberg, 2016). Chronic stress occurs when someone experiences stress for an extended period of time and is associated with increased cortisol output and flatter diurnal cortisol slopes (Broussard et al., 2015). This means that instead of cortisol levels peaking in the morning shortly after waking and falling throughout the day, a chronically stressed person's cortisol levels fail to fall, and they are exposed to even more cortisol (Cacioppo & Freberg, 2016).

Prolonged cortisol exposure is associated with many ailments. Cortisol inhibits immune function by blocking T-cells, the body's fundamental defense mechanism, from receiving interleukin signals increasing the risk of contracting an infection (Cacioppo & Freberg, 2016;

Randall, 2011). Cortisol also impairs insulin function, increasing blood sugar and promoting weight gain, which increases the risk of diabetes and obesity (Fraser et al., 1999). Excess cortisol also impairs memory by overwhelming cortisol receptors on the hippocampus, which is responsible for memory integration and storing the spatial context of memories (Cacioppo & Freberg, 2016; McEwen, 1998; Randall, 2011). Chronic exposure to cortisol is also linked to high blood pressure, high cholesterol, increased risk of heart disease, and decreased thyroid function (Fraser et al., 1999; Randall, 2011). In extreme cases, Cushing's Syndrome can result from very high levels of cortisol, where patients experience rapid weight gain, excessive sweating, and hypercalcemia (Randall, 2011).

The effects of stress are felt more highly in minorities, who are not only exposed to more environmental stressors than Whites (Brulle & Pellow, 2006; Gioielli, 2014; Zwickl et al., 2014), but still experience discrimination on a daily basis. Perceived discrimination is a self-reported feeling of discrimination in every day encounters, and minorities report perceived discrimination at much higher rates than Whites. Perceived discrimination can also be used as a qualitative measure of individual stress. Minorities of all age groups report perceived discrimination, from middle school to adulthood (Thayer & Kuzawa, 2015; Zeiders, Hoyt, & Adam, 2014). Even the infants of stressed minority mothers have higher stress reactivity when vaccinated (Thayer & Kuzawa, 2015), supporting theories that cortisol can pass through the placenta (Cacioppo & Freberg, 2016) and stress reactivity is heritable (Federenko et al., 2006).

A lifetime of stress and exposure to environmental contaminants has predictable health outcomes. The odds of African-American women giving birth to babies with low birth weights (< 2500 g) are almost three times as high as for White women, and the odds of African-American women giving birth to babies with very low birth weights (< 1500 g) are almost four times as

high as the odds for White women (Geronimus, 1996). African-American women are also more likely to have abnormal gestational weights, putting their infants at higher risk for developing respiratory disorders and type II diabetes (Mendez et al., 2014). African-Americans are more likely to develop diseases and conditions associated with exposure to ambient air pollution and cortisol, such as asthma, heart attacks, strokes, diabetes, and obesity, and are frequently more likely to die from these conditions than Whites (Centers for Disease Control and Prevention, 2012, 2014, 2015, 2016; Chen et al., 2016; Chum & O′Campo, 2013; Edwards & Myers, 2007; Fraser et al., 1999; Kim & Lee, 2014; McEwen, 1998; Sicotte & Swanson, 2007; US EPA, 2016). Overall, the life expectancy of African-Americans in the United States is 63.6 years, while the life expectancy for Whites is 70.6 years (Centers for Disease Control and Prevention, 2015), a difference equivalent to a 10% reduction in life expectancy.

As of yet, the literature lacks studies examining the intersection of race, stress, and health as it relates to environmental hazards. This paper will help fill that gap by answering the following questions: does stress affect the relationship between air pollution exposure and self-rated health in minorities? If so, how? We sought to answer these questions through a survey of Ohioans living near selected EPA-registered industrial facilities. We found that next to income, exercise and body mass index (BMI), stress was the strongest predictor of self-rated health. Stress was the strongest predictor of anxiety and the second strongest predictor of lung disease, after only income. While proximity to facilities was not shown to be a significant indicator in predicting health outcomes, future work should attempt to operationalize exposure to air toxins from nearby facilities in more nuanced ways, such as examining estimated exposure, as well as more precise location to air pollution emissions.

Methods

Data were obtained from a mail survey of Ohio residents in 2015. Addresses were obtained through a two-stage sampling procedure. In 2015, there were 2,309 industrial facilities in Ohio that are required to report to the Toxic Release Inventory (TRI) program run by the Environmental Protection Agency (EPA). Those facilities required to report are within certain industries like manufacturing, those with more than 10 employees, and those that use a regulated toxin. A random sample of 55 of these facilities was taken, then a random sample of 84 homes within those counties with a selected facility were obtained from the white pages, with an oversample of residents within a three-mile radius of the facility. The survey was sent to a total of 4,000 Ohioans, with a response rate of 18.63% (N=745) returned.

Because the number of responses from racial groups other than Black/African-American and White/Caucasian was very low, they were excluded from the analysis. Missing responses and participants who did not list a response for each variable considered in the analysis were also eliminated, bringing the number of responses down to 669 (16.73%). The final sample was approximately 84% White, 16% Black, and 57% female. This sample reflects racial demographics in Ohio, which is 82.5% White, 12.8% Black, and 51% female (U.S. Census Bureau, 2016).

The survey sought to evaluate participants' stress level over the past 30 days with the 10-item version of the Perceived Stress Scale (PSS) (see Appendix A), which is widely used in the literature (Roberti, Harrington, & Storch, 2006). For example, respondents were asked to rate how frequently they felt stressed in the previous 30 days using a Likert scale as well as responding to questions, such as in the last 30 days "how often have you felt that things were going your way?" and "how often have you felt that difficulties were piling up so high that you

could not overcome them?" These responses were coded so that high stress was input as a 5, and low stress was input as a 1. A mean stress score was calculated for each respondent with the overall mean equal to 3.05 and a standard deviation of 0.35.

The survey also asked participants to indicate which diseases they have been diagnosed with or taken medication for over the past year, with space to specify any marked "other." The "other" responses were manually reviewed to include participant responses that fell into listed categories but were not marked by the participant. For example, if a respondent did not check the box for lung disease, but wrote COPD or asthma in the "other" space, they were manually recoded for lung disease. Body mass index (BMI) was calculated using the height and weight of a respondent using equation 1 below.

Equation 1:

$$\text{BMI} = \frac{\text{Weight (kilograms)}}{[\text{Height (meters)}]^2}$$

The data were analyzed using multivariate regression in STATA 13.0. Models 1-9 presented below in Table 1 have different health outcome variables for the dependent variable. Model one's dependent variable is self-rated health, with respondents indicating in general whether their health was poor, fair, good, very good, or excellent, coded as 1 to 5 respectively. The dependent variables of models 2-8 are dichotomous variables for self-reported diagnosis of: lung disease, diabetes, arthritis, heart disease, high blood pressure, anxiety, and cancer. In the final model, a respondent was coded with a one if they reported being diagnosed with any of the disease outcomes evaluated in models 2-8. Independent variables utilized across models are mean stress, race, income, education level, sex, BMI, year born, exercise frequency, smoking status, and household distance from industrial facilities. Income was an ordinal variable of eight categories

measure income in intervals of $10,000, with 1 indicating an income of less than US$10,000 annually to over US$100,000. Education was coded from 1 to 5 indicating: did not graduate high school, high school graduate or GED, some college or associates degree, bachelor's degree, and graduate degree, respectively. Women were coded as two and men as one. Smoking status was coded as 1 if the respondents indicated they smoked every day, 2 if they smoked "sometimes" and 3 is they never smoked. Exercise was coded as 1 if they exercised and 0 if they did not. Finally, a variable was created to indicate participants' household distance from TRI-registered facilities, which was defined as being within three miles of a facility or not and was coded as the binary 1-0, respectively. Bivariate regression models alleviate concern about multicollinearity, with none of the variables in the model having a Pearson's correlation over 0.6. Autism, although included in the survey, was not included in the analysis because the sample size was very small (N=1) and results were not generalizable. Descriptive statistics can be viewed in Table 2.

Results

Results from the multivariate regression models shown in Table 1 explained 28% of the variance in self-rated general health. Overall, the strongest predictor of general health was one's mean stress level, with respondent's health significantly decreasing with every 0.44 unit increase in their mean stress level. The second strongest predictor was whether a respondent was Black or White with African-Americans being associated with significantly worse health than Whites. Whether or not a respondent resided within three miles of a facility was positively and significantly (p-value=0.04) associated with worse health. Income was significantly protective of health, along with being born more recently, smoking less, exercising more, and having a lower BMI.

Models 2-8 show similar patterns in the importance of these control variables. Older respondents were significantly more likely to have every health outcome with the exception of anxiety. Higher BMI was a significant indicator of all health outcomes with the exception of cancer and lung and heart disease. Smoking status, exercise, and education were surprisingly not that strongly predictive of health outcomes; education was not significantly associated with any of the outcome variables and more exercise was significantly and positively related to better self-reported general health but negatively related to heart disease and hypertension. Smoking status was not a significant predictor of health across models but was positively and slightly significantly related to better self-rated health (p-value=0.02). In general, there were no differences between genders, with the exception of anxiety, whereby women were slightly more likely to report being diagnosed with anxiety compared to men.

Our major independent variables (stress, race, proximity to facility, and income) show some interesting patterns in their predictive value across models. While living within 3 miles of a facility was positively and significantly related to poorer self-rated general health, it was not found to be predictive of any of the health outcomes individually or in aggregate. Stress, on the other hand, showed to be strongly related to self-rated health and anxiety, as well as a slightly significant indicator of self-reported diagnosis of heart disease. In general, race was not a significant indicator of health outcomes, with the exception of general health and anxiety, which demonstrate that African Americans are likely to be significantly worse off when compared to Whites in self-rated general health but better off than Whites when looking at anxiety. Results show income has a protective effect on health across models, with those reporting higher income slightly significantly less likely to report a diagnosis of anxiety, diabetes, and lung disease. However, higher income was strongly related (p-value=0.000) to better self-reported health.

A sensitivity analysis was done to test the interactions between stress and race, and race and proximity to industrial facilities. When the regression was run including the interaction variable for race and proximity to industrial facilities, arthritis became significantly associated with not only age and BMI, but also strongly positively associated minority status, household proximity to industrial facilities, and the interaction between the two. The interaction between stress and race was not significant for arthritis or any other health outcomes, so it was not included in this analysis. The sensitivity analysis for either interaction was not significant for any other health outcomes, so they were also excluded from this analysis.

Table 1. Results from Ordered Logit Regression Models Predicting Self-Rated Health

	Model 1				Model 2				Model 3				Model 4			
Dependent Variable	**General Health**				**Arthritis (Yes=128)**				**Lung Disease (yes=23)**				**Heart Disease (Yes=61)**			
	Coef.		*SE*	*P Value*	*Coef.*		*SE*	*P Value*	*Coef.*		*SE*	*P Value*	*Coef.*		*SE*	*P Value*
Mean Stress	-0.43	***	0.08	0.00	0.01		0.04	0.70	0.02		0.02	0.21	0.06	*	0.03	0.04
Race (Black=1) (White=0)	-0.26	*	0.10	0.02	0.05		0.05	0.30	-0.01		0.02	0.52	-0.01		0.04	0.78
Proximity (1=3mi or less)	0.18	*	0.09	0.04	-0.06		0.04	0.16	-0.01		0.02	0.45	0.03		0.03	0.28
Income	0.06	***	0.02	0.00	0.00		0.01	0.85	-0.01	+	0.00	0.08	-0.01		0.01	0.43
Year Born	0.01	***	0.00	0.00	-0.01	***	0.00	0.00	0.00	*	0.00	0.01	0.00	***	0.00	0.00
Sex (1=male 2=female)	0.06		0.07	0.40	0.05		0.03	0.12	0.00		0.01	0.84	-0.04		0.02	0.13
BMI	-0.03	***	0.00	0.00	0.01	***	0.00	0.00	0.00		0.00	0.74	0.00		0.00	0.98
Smoking Status	0.13	*	0.06	0.02	0.00		0.03	0.98	-0.02		0.01	0.17	0.00		0.02	0.92
Exercise (yes=1) (0=no)	0.25	*	0.10	0.01	-0.03		0.05	0.47	-0.03		0.02	0.16	-0.05	*	0.03	0.13
Education	0.04		0.03	0.29	-0.01		0.02	0.42	-0.01		0.01	0.44	-0.02		0.01	0.16
Constant	-12.71	***	4.08	0.00	14.52	***	2.02	0.00	2.31	*	0.88	0.01	9.58	***	1.46	0.00
R Squared			0.28				0.16				0.06				0.14	
N (Respondents)			465				462				462				462	

	Model 5				Model 6				Model 7				Model 8				Model 9			
Dependent Variable	**Hypertension (yes=218)**				**Diabetes (yes=80)**				**Anxiety (yes=104)**				**Cancer (yes=36)**				**Any Condition (Yes=375)**			
	Coef.		*SE*	*P Value*	*Coef.*		*SE*	*P Value*	*Coef.*		*SE*	*P Value*	*Coef.*		*SE*	*P Value*	*Coef.*		*SE*	*P Value*
Mean Stress	0.01		0.04	0.89	-0.04		0.03	0.27	0.16	**	0.04	0.00	0.00		0.02	0.90	0.05		0.05	0.26
Race (Black=1) (White=0)	0.08		0.06	0.18	0.07		0.04	0.13	-0.09	+	0.05	0.08	0.02		0.03	0.59	0.04		0.06	0.51
Proximity (1=3mi or less)	0.01		0.05	0.91	-0.04		0.04	0.30	-0.07		0.04	0.12	-0.02		0.03	0.34	-0.07		0.05	0.17
Income	-0.01		0.01	0.30	-0.02	+	0.01	0.01	-0.02	*	0.01	0.05	0.00		0.01	0.73	-0.01		0.01	0.21
Year Born	-0.01	***	0.00	0.00	0.00	***	0.00	0.00	0.00		0.00	0.39	0.00	***	0.00	0.00	-0.01	***	0.00	0.00
Sex (1=male 2=female)	-0.03		0.04	0.47	-0.01		0.03	0.77	0.09	*	0.03	0.01	0.02		0.02	0.45	0.02		0.04	0.72
BMI	0.01	***	0.00	0.00	0.01	***	0.00	0.00	0.01	*	0.00	0.01	0.00		0.00	0.99	0.01	***	0.00	0.00
Smoking Status	-0.02		0.03	0.56	0.04	+	0.02	0.07	-0.04		0.03	0.19	0.01		0.02	0.58	-0.03		0.03	0.40
Exercise (yes=1) (0=no)	-0.10	+	0.05	0.08	0.00		0.04	0.95	-0.02		0.05	0.60	0.01		0.03	0.85	-0.08		0.06	0.16
Education	0.03		0.02	0.16	0.02		0.01	0.23	0.03	+	0.02	0.07	-0.01		0.01	0.59	0.03		0.02	0.16
Constant	22.45	***	2.29	0.00	8.77		1.72	0.00	-2.08		1.99	0.30	3.96		1.19	0.00	24.07		2.47	0.00
R Squared			0.24				0.17				0.10				0.04				0.24	
N (Respondents)			462				462				462				477				484	

Source: Neighborhood Survey, 2015

Note: All models include additional control variables for age, sex, BMI, smoking status, education, and exercise frequency. Regression

***p < 0.001; **p < 0.01; * p < 0.05; + p < 0.10

Table 2. Descriptive Statistics

Variable	N	Mean	Std. Dev.	Min	Max
Mean Stress	636	3.05	0.35	1.30	4.40
Race (Black=2) (White=1)	671	1.16	0.36	1.00	2.00
Proximity (1=3 mi or less)	669	0.83	0.37	0.00	1.00
Income	620	5.73	2.23	1.00	9.00
Year Born	642	1959.70	17.31	1917	1996
Sex (1=male 2=female)	670	1.57	0.50	1.00	2.00
BMI	644	27.92	6.78	0.00	70.85
Smoking Status (never=1 everyday=3)	639	1.26	0.64	1.00	3.00
Exercise (yes=2) (no=1)	645	1.18	0.38	1.00	2.00
Education	664	5.67	1.90	1.00	8.00

Discussion and Conclusions

This study addresses a gap in the literature examining how stress impacts the relationship between self-reported health outcomes and air pollution exposure in minorities. In general, proximity to industrial facilities was not a strong predictor of health outcomes, with the exception of perceived health where those respondents living within three miles of an industrial facility reported moderately worse general health (p-value=0.04). The fact that there was any significant difference found between individuals living closer to facilities and those father away with such a crude indicator of exposure to toxins warrants future examination into these relationships. While interactions between race, stress, and exposure were not shown to be significant, previous literature has shown that poor and minority communities are more likely to live closer to industrial facilities (Bullard, Mohai, Saha, & Wright, 2007) and these communities are likely more stressed due to financial strain. Future work should investigate these relationships further with more refined measures of exposure to pollutants and types of stress.

Results demonstrate that stress negatively impacts perceived general health and anxiety. However, we did not find support that it significantly impacted other health outcomes. The relationship between stress and anxiety, although statistically significant and strong, was expected based on the definition of anxiety as "excessive, out of control worry" (Locke, Kirst, & Shultz, 2015) and is therefore somewhat unremarkable. Black respondents fared significantly worse than White respondents in self-rated general health but were not more likely to have any of the health outcomes we examined individually or in total. This suggests that perceptions of health may be influenced by factors not included in this analysis, or that the way of framing the question hindered individuals who do not seek or have access to regular medical care from indicating they had a given condition. White respondents fared slightly worse than Black respondents in anxiety. However, the literature on mental health says there is differential access to and use of mental health services among racial groups, particularly that minority groups are less likely than Whites to utilize mental health services (Zuvekas & Fleishman, 2008). Thus, there is the potential for underdiagnosis of mental health disorders in these communities, which could influence these results by "ignoring" participants without a formal diagnosis and skewing results towards the null model. Similarly, proximity to facilities was predictive of poorer self-rated general health but was not associated with any health outcomes. This is consistent with work finding that perceptions of air pollution and health risks associated with it are rooted in personal and social experiences with pollution (Bickerstaff & Walker, 2001). Overall, health outcomes were best predicted by "classic" biologic indicators, such as age and BMI, and were somewhat well predicted by socioeconomic determinants of health. Being older was positively associated with all health outcomes except anxiety, which is consistent with the literature on normal aging revealing that physical ability decreases and morbidity increases with age (Beswick

et al., 2008). The association between increased BMI and all health indicators except cancer and lung disease was not unsurprising, but BMI not being a strong predictor of heart disease was unexpected (National Institutes of Health, n.d.). BMI is a well-established metric for heart disease risk, although recent research has revealed that waist circumference may be a more reliable measure (Gujral et al., 2017; Janssen, Katzmarzyk, & Ross, 2004; National Institutes of Health, n.d.) and there is some evidence to suggest that BMI may not be as reliable a predictor of heart disease in minorities as it is in Whites (Gujral et al., 2017). Income was a protective factor for diabetes, anxiety, and lung disease and was strongly protective for self-rated general health. This is consistent with a large body of evidence to support a strong relationship between poverty and increased prevalence and incidence of diabetes (Beckles & Chou, 2013; Levine, 2011; Rabi et al., 2006), a growing body of evidence suggesting the same relationship between income and lung disease (Kanervisto et al., 2011; Sahni, Talwar, Khanijo, & Talwar, 2017), and a less robust but still positive association between low income and anxiety (Sareen, Afifi, McMillan, & Asmundson, 2011; Vine et al., 2012).

There were a few unexpected relationships represented in these data that do not follow previous work. For example, education was not a significant predictor of any of the health outcome variables. This is at odds with a large volume of research detailing health disparities along educational lines (Braveman, Cubbin, Egerter, Williams, & Pamuk, 2010; Fiscella & Kitzman, 2009; Mensah, Mokdad, Ford, Greenlund, & Croft, 2005). This could have been due to the way that education was coded. There were eight education categories, ranging from "less than 9^{th} grade" to "graduate degree." This may simply be too many categories for our small sample size, weakening our results. Also surprising was the lack of effect of smoking status on health outcomes besides a slightly protective effect on general health. Smoking is a well-known

risk factor for many diseases, including lung disease, heart disease, and types of cancer (Centers for Disease Control and Prevention, 2018). However, in the survey, smoking status was only able to be identified as "never," "sometimes," or "every day," and did not account for past smoking history. This could have artificially decreased the strength of the relationship between lung disease and smoking status. Another surprising result was that of exercise. It was expected that respondents who exercised would have better health, but in reality exercise was only slightly protective of general health and actually had a small negative association with heart disease and hypertension. However, this may be because physicians strongly encourage patients with heart disease and hypertension to exercise more to avoid complications from their diagnoses (Centers for Disease Control and Prevention, 2013; Khan, Weiler, & Blair, 2011; Seth, 2014). Additionally, our measure of physical activity is imperfect. The question (see Appendix A, page 23) asked "do you or those in your household take part in any of the following activities that might be within walking distance of your home?" Response options were "yes", "no", and "not available." This means we did not directly measure whether respondents exercised, nor did we measure their exercise frequency. Additionally, participants may have selected "not available" if opportunities to exercise were not within walking distance of their home, regardless of whether or not they exercise.

This study is limited by several factors. First is the small sample size, which limited the number of diseases that could be analyzed and the minority groups that could be included in the analysis. Although intentional, this study oversampled people living near industrial facilities. However, this meant the control group may not be as useful a baseline as people who do not live near industrial facilities and could skew results towards the null model by minimizing differences between respondents. There were also several confounding variables that were not

included in the survey, including alcohol consumption, illicit drug use, proximity to major roadways, and, perhaps most importantly, insurance status. Because the questionnaire asked about diagnosed illness, those individuals without health insurance are less likely to have seen a doctor where such a diagnosis could be made.

Despite these limitations, it was striking how well Model 1 explained self-reported general health, with almost 30% of the variation in general health explained by our independent variables. For our particular focus on pollution and stress, we see that those individuals reporting worse stress were strongly more likely to report worse health and those individuals living nearer to facilities were moderately more likely to report worse overall health. These results support the argument that the historic discrimination impacting communities around these sites might be negatively influencing these individuals health, contributing to health disparities by class and race. Future work should improve upon these analyses by examining plume effects, which are the typical distribution of air pollutants based on prevailing winds and other patterns (Husar & Patterson, 1980), and analyzing home distance to facilities as a gradient instead of a binary variable. In addition, more work is needed to determine the effects of race and stress on mental health, cognitive disorders, and cancers as they relate to exposure to environmental hazards. Future work should work to better characterize duration and composition of industrial air toxin exposure by incorporating the length of time participants have lived at their current address, where and for how long they lived at previous addresses, and their place(s) of employment.

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Appendix A

SECTION A: YOU & YOUR NEIGHBORHOOD

1. Are any of the following places within walking distance of your home?

Parks or recreation areas	☐ Yes	☐ No
Industrial areas or factories	☐ Yes	☐ No
Major roadways	☐ Yes	☐ No

2. Can you see any of the following places from your home?

Parks or recreation areas	☐ Yes	☐ No
Industrial areas or factories	☐ Yes	☐ No
Major roadways	☐ Yes	☐ No

3. Do you or those in your household take part in any of the following activities that might be within walking distance of your home?

Fishing	☐ Yes	☐ No	☐ Not Available
Berry / mushroom / nut hunting	☐ Yes	☐ No	☐ Not Available
Hunting any type of game species	☐ Yes	☐ No	☐ Not Available
Walking, running or other exercise activities	☐ Yes	☐ No	☐ Not Available
Relatives living nearby	☐ Yes	☐ No	☐ Not Available

4. Please indicate your level of agreement or disagreement with each statement below.

	Strongly Agree	Agree	Neither	Disagree	Strongly Disagree
Living here is more important than living any other place.	☐	☐	☐	☐	☐
I identify strongly with my neighborhood.	☐	☐	☐	☐	☐
I am very attached to the natural environment of my neighborhood.	☐	☐	☐	☐	☐
I am very attached to the people in my neighborhood.	☐	☐	☐	☐	☐

5. Approximately how long have you lived at your current address? _____

6. Do you rent your home? ☐ Yes ☐ No

7. What is your average rent or mortgage? _____/month

8. In the last year, have you provided or received any of the following from friends, neighbors or relatives that do not live with you but live in your neighborhood?

	Provided	Received	Neither
Help with shopping or running errands	☐	☐	☐
Transportation	☐	☐	☐
Help with housework, home or car repair	☐	☐	☐
Childcare	☐	☐	☐
Food purchased at the store	☐	☐	☐
Food grown/caught/hunted/foraged	☐	☐	☐

9. Below is a list of reasons why someone might move to a new neighborhood. Please tell us how important each of the following items were in your choice to move to your current residence. ☐ Not Applicable (I have only lived in this house).

	Unimportant	Of Little Importance	Moderately Important	Important	Very Important	N/A
To be close to my work or my partner's work	☐	☐	☐	☐	☐	☐
To be close to my family	☐	☐	☐	☐	☐	☐
To be close to my friends	☐	☐	☐	☐	☐	☐
To be close to recreation	☐	☐	☐	☐	☐	☐
To be close to social opportunities	☐	☐	☐	☐	☐	☐
Cheaper rent/ mortgage	☐	☐	☐	☐	☐	☐
The atmosphere of this neighborhood	☐	☐	☐	☐	☐	☐

10. Thinking about neighborhoods in the U.S. in which you have previously lived, how did they compare to your current area? ☐ Not Applicable (I have only lived in this house).

Previous Address Please list as much information as you can recall	**What year(s) did you live there?**	**Compared to Your Current Neighborhood Your Previous Neighborhood Was:**				
		Mostly Worse	Slightly Worse	The Same	Slightly Better	Mostly Better
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
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		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐

SECTION B: YOUR HEALTH & WELLBEING

We are interested in understanding more about your health and wellbeing.

1. First, we need some basic information:

a) **What is your sex?** ☐ Male ☐ Female

b) **What year were you born?** _____

c) **What is your height?** _____feet _____inches

d) **What is your typical weight?**_____pounds

e) **How much schooling have you completed?**

☐ Less than 9th grade
☐ Some high school, but no diploma
☐ High school graduate or GED
☐ Some college, business, or technical school
☐ Associate's degree
☐ Bachelor's degree
☐ Graduate degree (MS, MD, JD, PhD)

f) **What is your race/ethnicity?**

☐ White/Caucasian
☐ Black/African-American
☐ Hispanic/Latino
☐ Asian/Pacific Islander
☐ Native American
☐ Other (please specify)_____

g) **When it comes to politics do you usually think of yourself as:**

Extremely Liberal	Liberal	Slightly Liberal	Moderate, Middle of Road	Slightly Conservative	Conservative	Extremely Conservative
☐	☐	☐	☐	☐	☐	☐

2. In general would you say your health is:

☐ Excellent ☐ Very Good ☐ Good ☐ Fair ☐ Poor

3. Do you have children?

☐ No ☐ Yes → If yes, do they live with you? ☐ No ☐ Yes → If yes, what are their ages?

Ages: _____ _____ _____ _____ _____ _____ _____

_____ _____ _____ _____ _____ _____ _____

4. How often do you smoke cigarettes? ☐ Never ☐ Sometimes ☐ Every day

5. Please check the box next to the condition(s) that you have been diagnosed with, or taken medication for, over the past year. ☐ Not applicable

☐ Arthritis or Rheumatism
☐ Lung disease
☐ A heart attack or other heart trouble
☐ Hypertension/high blood pressure
☐ Diabetes or high blood sugar
☐ Anxiety or Depression
☐ Autism
☐ ADHD
☐ Cancer or malignant tumor *(please specify type)* _____
☐ Other (*please specify*) _____

6. Please check the box next to the condition(s) that anyone in your household has been diagnosed with, or taken medication for, over the past year. ☐ Not applicable

☐ Arthritis or Rheumatism
☐ Lung disease
☐ A heart attack or other heart trouble
☐ Hypertension/high blood pressure
☐ Diabetes or high blood sugar
☐ Anxiety or Depression
☐ Autism
☐ ADHD
☐ Cancer or malignant tumor *(please specify type)* _____
☐ Other (*please specify*) _____

7. If you are employed, how long does it take you to get to your primary place of work?

☐ Not employed ☐ 1 – 15 minutes ☐ 31 – 60 minutes ☐ 91+ minutes
☐ On disability ☐ 16 – 30 minutes ☐ 61 – 90 minutes ☐ Work from home/retired

8. If you are employed, what is your primary mode of transportation to and from work?

☐ Not applicable ☐ Public transportation (bus, shuttle, rideshare, carpool)
☐ I work from home ☐ Walking
☐ Personal automobile ☐ Bicycling

9. Are you or anyone in your home employed by an industrial facility? ☐ Yes ☐ No

10. What is your approximate annual household income from all sources before taxes? (Please check one)

☐ Less than $10,000 ☐ $25,000 - $34,999 ☐ $75,000 - $99,999
☐ $10,000 – $14,999 ☐ $35,000 - $49,999 ☐ $100,000 - $149,999
☐ $15,000 - $24,999 ☐ $50,000 - $74,999 ☐ $150,000 or more

11. The following questions ask about your feelings & thoughts during the past month.

In the past month:	Never	Almost Never	Some times	Fairly Often	Very Often
How often have you been upset because of something that happened unexpectedly?	☐	☐	☐	☐	☐
How often have you felt unable to control the important things in your life?	☐	☐	☐	☐	☐
How often have you felt nervous or stressed?	☐	☐	☐	☐	☐
How often have you felt confident about your ability to handle personal problems?	☐	☐	☐	☐	☐
How often have you felt that things were going your way?	☐	☐	☐	☐	☐
How often have you found that you could not cope with all the things you had to do?	☐	☐	☐	☐	☐
How often have you been able to control irritations in your life?	☐	☐	☐	☐	☐
How often have you felt that you were on top of things	☐	☐	☐	☐	☐
How often have you been angry because of things that happened that were outside of your control?	☐	☐	☐	☐	☐
How often have you felt that difficulties were piling up so high that you could not overcome them?	☐	☐	☐	☐	☐

SECTION C: YOUR OPINIONS

1. Please tell us how much you agree or disagree with each of these statements.

	Strongly Disagree	Slightly Disagree	Neither	Slightly Agree	Strongly Agree
I feel stressed when I see industrial facilities/factories in my neighborhood.	☐	☐	☐	☐	☐
We worry too much about the future of the environment, and not enough about prices and jobs today.	☐	☐	☐	☐	☐
People worry too much about human progress harming the environment.	☐	☐	☐	☐	☐
There are more important things to do in life than protect the environment.	☐	☐	☐	☐	☐
Many of the claims about environmental threats are exaggerated.	☐	☐	☐	☐	☐
Air pollution is dangerous to me and my family's health.	☐	☐	☐	☐	☐
Modern science will solve environmental problems.	☐	☐	☐	☐	☐

2. In general, how often do you do the following:

	Always	Often	Some-times	Never	N/A
Cut back on driving a car for environmental reasons.	☐	☐	☐	☐	☐
Sort glass or cans or plastic or papers and so on for recycling.	☐	☐	☐	☐	☐
Buy fruits and vegetables grown without pesticides/chemicals.	☐	☐	☐	☐	☐
Reduce the energy or fuel you use at home for environmental reasons.	☐	☐	☐	☐	☐
Save or re-use water for environmental reasons.	☐	☐	☐	☐	☐
Avoid buying certain products for environmental reasons.	☐	☐	☐	☐	☐
Vote for a candidate because of their stance on the environment.	☐	☐	☐	☐	☐

3. How dangerous do you think that the following items are to you and your family's health:

	Not at all dangerous	Not dangerous	Somewhat dangerous	Dangerous	Very dangerous
Air pollution by cars.	0	1	2	3	4
Air pollution by industry.	0	1	2	3	4
Pesticides/chemicals used in farming.	0	1	2	3	4
Pollution of rivers, lakes and streams.	0	1	2	3	4
Modifying the genes of certain crops.	0	1	2	3	4

4. Are you currently registered to vote? ☐ Yes ☐ No ☐ I don't know ☐ I can't register

5. Are you a member of any group whose main aim is to preserve/protect the environment?
☐ Yes ☐ No

6. In the last five years, have you:

Taken part in a protest or demonstration about an environmental issue? ☐ Yes ☐ No

Given money to an environmental group? ☐ Yes ☐ No

Signed a petition about an environmental issue? ☐ Yes ☐ No

Thank you for your input! Please let us know if you have any additional thoughts.

_____

_____

_____

When you are finished filling out this questionnaire simply drop it in the mail with the pre-paid envelope to:
Neighborhood Survey, 210 Kottman, OSU, 2021 Coffey Rd Columbus, Ohio 43210